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# *A MEDICAL PLANNING TOOL FOR PROJECTING THE REQUIRED CASUALTY EVACUATION ASSETS IN A MILITARY THEATER OF OPERATIONS*

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**A Medical Planning Tool for Projecting the Required Casualty Evacuation Assets in a Military Theater of Operations**

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## SUMMARY

Problem

Military medical readiness for combat deployments requires prepositioning the necessary medical treatment facilities (MTFs) and casualty evacuation assets within the theater of operations. Determining the best locations and minimum number of transportation assets depends on prior knowledge of the appropriate planning evacuation policy, each of the troop locations and evacuation routes, and reliable casualty rates.

Objective

The present report documents a medical planning tool (called OPTEVAC) designed to determine the optimum placement and minimum numbers of ground evacuation assets across a theater of operations. Guidance is provided on OPTEVAC operation, and a detailed description is given for the algorithms and statistical assumptions on which it is based.

Approach

Source code was written in the C and C++ programming languages to implement OPTEVAC's algorithms and graphical user interface (GUI). Proper operation procedures were fully documented to make the software as user-friendly as possible.

Results

Iterative algorithms based on typical evacuation policies and empirical length of treatment data were designed to calculate theater bed requirements. The Probabilistic Location Set Covering Integer Program (PLSCIP) was devised to calculate the minimum ground evacuation asset requirements. PLSCIP output is based on the anticipated casualty load, the distances to be traversed, and asset availability. A series of data input screens prompts the user for all of the planning factors needed to make these important calculations. When OPTEVAC was tested, it was found to perform especially well for large casualty loads.

Conclusions

Determining the minimum evacuation asset requirements for a military operation depends on a large number of user-entered planning factors. The OPTEVAC medical planning tool implements optimization algorithms, which will enable medical logisticians to accurately project the evacuation demands of future combat scenarios.

## A Medical Planning Tool for Projecting the Required Casualty Evacuation Assets in a Military Theater of Operations

Medical readiness for ground combat operations depends on accurate casualty projections, determination of bed requirements, and assessments of the evacuation assets needed to efficiently move the injured through the medical treatment system. A previously developed medical planning tool, FORECAS,[1] provides scenario-specific projections of the expected wounded in action (WIA) and disease and non-battle injury (DNBI) admissions. Furthermore, a preliminary evacuation asset siting algorithm called the Probabilistic Location Set Covering Problem, or PLSCP,[2,3] was analyzed and tested in a previous report.[4] The goal of the current effort is to describe the correct operation of the Optimal Placement of Casualty Evacuation Assets simulation tool (called OPTEVAC) and each of its underlying algorithms.

When using the OPTEVAC simulation tool, the planner is first requested to enter many critical operational factors needed to project the bed and casualty transportation requirements. These factors include the expected length of the operation, the evacuation delay and theater evacuation policy, the size of the theater, the troop strength at each deployment location, the projected WIA and DNBI average daily rates, the desired casualty load, the locations of the Echelon II and III medical treatment facilities (MTFs) along with the troop deployment locations they service, and the expected availability of each type of evacuation ambulance. Bed requirement projections for Echelons II and III are based on the expected numbers of daily casualties, their expected length of treatment,[5] the evacuation delay, and the theater evacuation policy. OPTEVAC uses the remaining planning data to distribute the minimum required numbers of each available transportation asset at the most appropriate locations throughout Echelons II and III. A modified version of the PLSCP, referred to as the Probabilistic Location Set Covering Integer Program (PLSCIP) in this report, is the primary algorithm on which OPTEVAC is based. The PLSCIP's evacuation asset projections are based on the specified locations of demand, the distances to be traversed between the MTFs and their associated collection points, and evacuation asset availability.[2]

The OPTEVAC software is designed to be a tool for planners in assessing the medical requirements for combat operations. The accurate identification of the minimum required numbers, types, and deployment locations of the available evacuation assets will ensure that wounded personnel are transported efficiently between the collection point and the appropriate MTF at each echelon. Furthermore, while the methodology was developed for Marine Corps deployments, which rely solely on vehicles of opportunity, OPTEVAC was flexibly designed to allow other services to incorporate their treatment facilities and evacuation asset types as well.

The present document, comprising three sections and an Appendix, provides a detailed description of the OPTEVAC simulation tool. Part I displays the software's graphical user interface (GUI). This section illustrates how to operate each data input and output screen. Furthermore, all displayed screen information is formally defined. Part II presents OPTEVAC's underlying mathematical and statistical algorithms. Part III verifies this planning tool's projections for a simple operational scenario. Finally, the Appendix details its installation, setup, and general program commands.

## PART I – USE OF THE OPTEVAC SIMULATOR

The first input screen, the Length of Operation screen (*Figure 1*), prompts the user to enter information pertaining to the anticipated length of the planned operation. The user enters the projected length of the operation and clicks on OK with the left-hand button (LHB) on the mouse to proceed to the next screen.

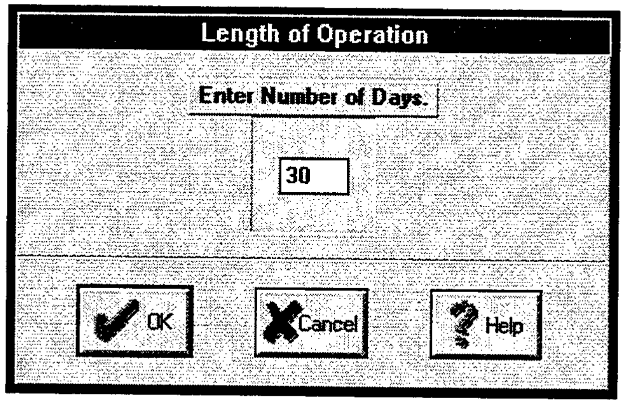



*Figure 1.* Length of Operation screen.

The Operation Parameters screen, shown in *Figure 2*, prompts the user for the factors needed to calculate the bed totals and minimum number of assets. The first quantity, the percentage of the maximum likely patient load, specifies the expected casualty load for the operation. Since casualty incidence on a day-to-day basis may demonstrate a great deal of variability, it is resource efficient to provide planners with a mechanism for choosing a *percentage* of the maximum expected daily patient load. This entered value allows the medical planner to avoid designating additional evacuation assets that would only be needed on the relatively rare occurrences of extreme casualty pulses. Entering a value between 80 and 99% instead would require MTFs to rely on vehicles of opportunity to meet the transportation demands of the high casualty pulse days.

The second entry on this screen is the 2nd Echelon Delay (or Evacuation Delay), measured in days. The Evacuation Delay is typically set before the operation commences, and it may vary depending on the theater location, manpower requirements, and other operational considerations. More specifically, it is the maximum amount of time that a patient will be retained at an Echelon II level of care before being returned to duty or

transferred to another facility. Thus, raising the Evacuation Delay will cause a greater accumulation of patients in the forward care units, and likewise, require a larger number of available beds.[6,7]

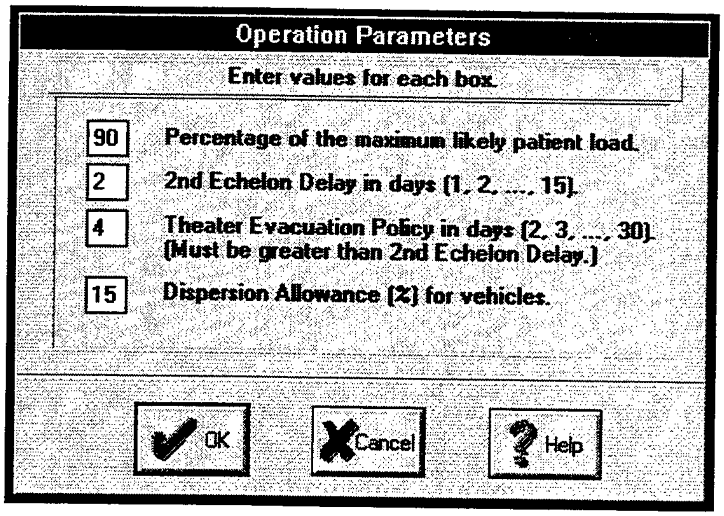



*Figure 2.* Operation Parameters screen.

The third quantity, the Theater Evacuation Policy, is a theaterwide value representing the maximum number of days a patient is retained within the theater of operations when the patient is likely to return to duty following treatment.[7] This screen accepts values between 2 and 30 days.

The final entry on this screen, the Dispersion Allowance, is needed to incorporate uncertainty in vehicle availability. This quantity is the projected percentage of evacuation vehicles in the force that will be unavailable for missions due to maintenance, crew rest, combat loss, or replacement lag time.[8] Accepted values range between 0 and 99%, but typically average between 10 and 30%.

The Theater Size screen (*Figure 3*) requests information on the theater dimensions. On the right side of the screen, the user has the option to choose the desired units of distance, either kilometers (km) or miles. If the user does not specify a unit of measure, the default unit is kilometers.

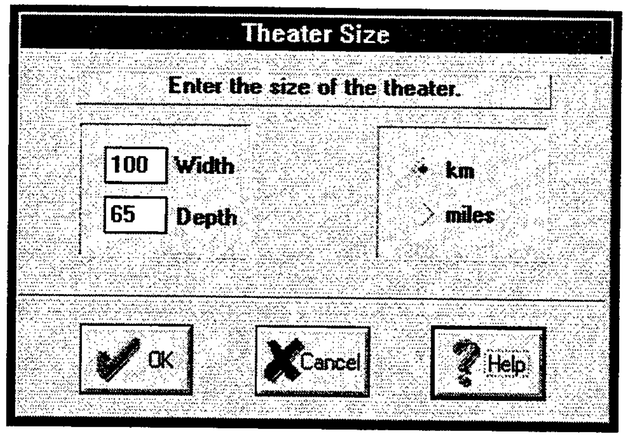



*Figure 3.* Theater Size screen.

On the left side of the screen, the user enters the specific values of distance. The first dimension, the Width, measures the horizontal, or left-to-right distance of the proposed theater. The second dimension, Depth, measures the vertical distance starting from the

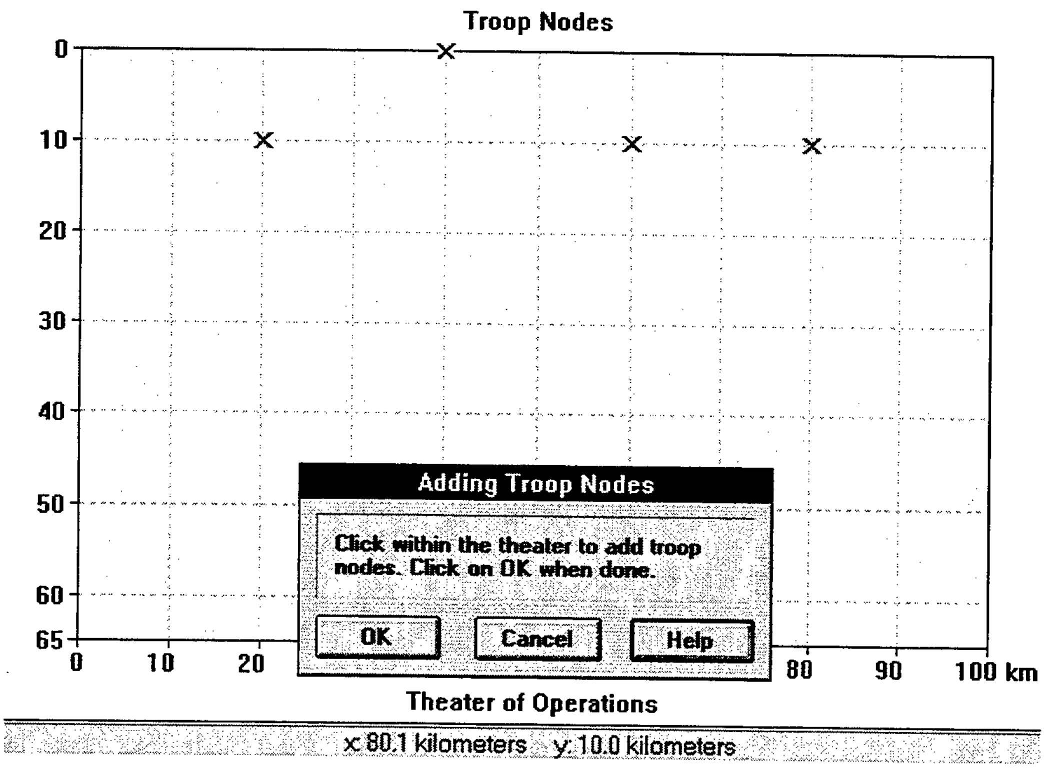



*Figure 4.* Adding Troop Nodes screen.

line of battle to the bottom edge of the theater. Once the desired values have been entered, the user clicks on the OK button with the LHB, and then the simulation will generate and display the theater with the entered dimensions.

The Adding Troop Nodes screen (*Figure 4*) asks the user to place each of the Troop Node sites. Each Troop Node is defined as a collection point for any nearby casualties that elapse over the duration of the operation. To place each of these nodes, the user must move the mouse cursor within the theater to the desired position. Clicking the mouse with the LHB will place a green "X" at the current mouse cursor position.

As the user moves the mouse cursor throughout the theater, its horizontal and vertical coordinates (measured in the previously specified units) are displayed on the gray Message Bar, located at the very bottom of the screen for easy reference (see *Figure 4*). The "x-coordinate" represents the horizontal (width) distance, while the "y-coordinate" represents the vertical (depth) distance (both distances are measured from the upper left-hand corner of the theater). Once all of the Troop Nodes are placed, the user must then click on the OK button with the LHB to advance to the next process. A scenario involving four Troop Nodes is depicted in *Figure 4* (the coordinates displayed in the Message Bar represent the position of Troop Node #4 in this example).

The Populate Troop Nodes screen (*Figure 5*) prompts the user to enter the troop strength for each Troop Node. In this example, a troop strength of 1000 was entered for Troop Node #1. To enter data for the next Troop Node, the user must press the OK button with the LHB. This process will repeat until all of the Troop Nodes for the given theater have a corresponding troop strength. Pressing the OK button with the LHB after entering data for the last Troop Node will advance the user to the next process.

Once all of the Troop Nodes are populated, the user is prompted to enter the anticipated average daily WIA and DNBI casualty rates for each node. OPTEVAC accepts rates between 0 and 100 casualties per 1000 strength per day, and may be entered within two decimal places of accuracy. The Casualty Rates screen in *Figure 6* displays a WIA rate of 4.50 and a DNBI rate of 2.20 for Troop Node #1. Then the user must click on the Next button with the LHB to enter data for the next Troop Node. This process will

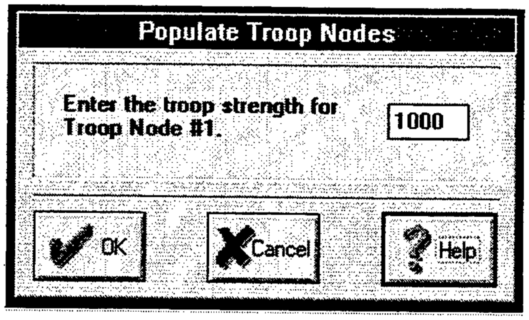



*Figure 5.* Populate Troop Nodes Screen.

repeat until each Troop Node has either a WIA rate, a DNBI rate, or both. After the troop strength and casualty rate data have been entered, the simulation generates the casualty totals, and the Casualties Generated screen notifies the user this calculation is complete (see *Figure 7*).

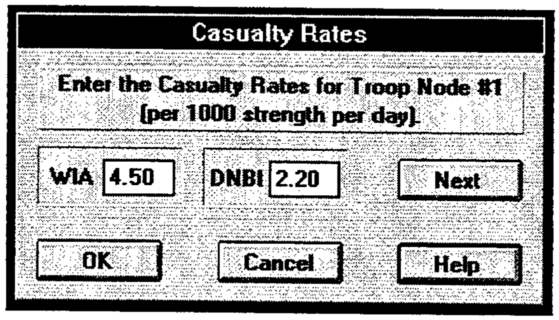



*Figure 6.* Casualty Rates screen.

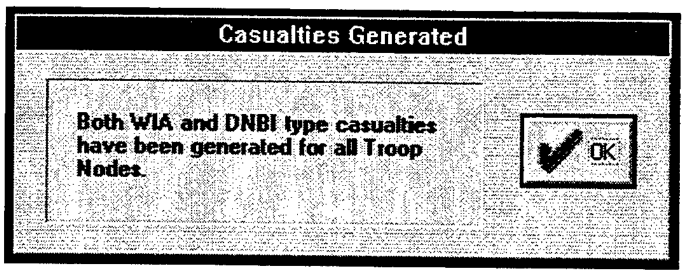



*Figure 7.* Casualties Generated screen.

The Bed Count Warning screen (*Figure 8*) advises the user about the number of 2nd Echelon beds required to accommodate the projected casualties for at least 90% of the

days of the operation. For example, the following warning screen states that 106 2nd Echelon beds are required to accommodate the total casualty load.

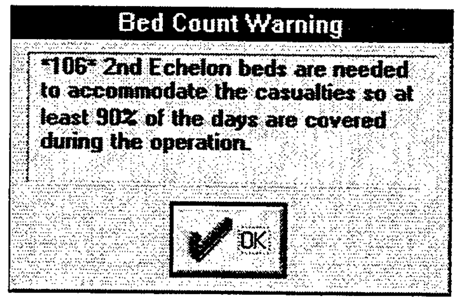



*Figure 8.* Bed Count Warning screen.

The user then places the desired number of 2nd Echelon MTFs on the displayed grid of the Adding 2nd Echelon Units screen (*Figure 9*). This is done by moving the mouse cursor to the desired position within the theater. Both the horizontal and vertical coordinates are displayed to indicate the current position on the bottom Menu Bar as the

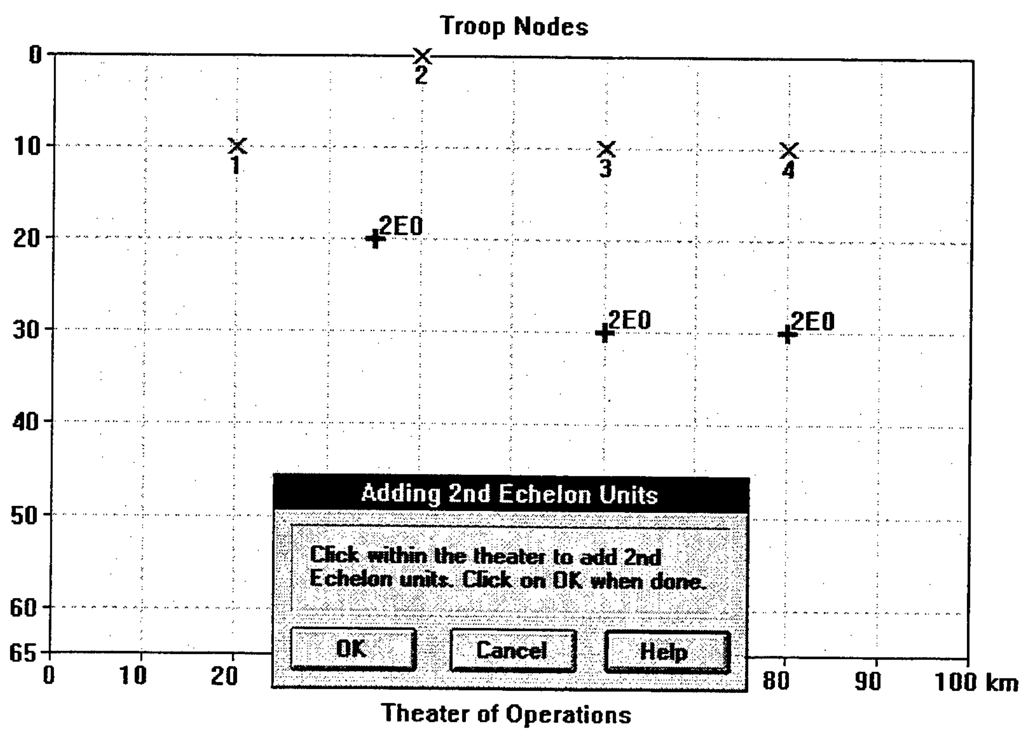



*Figure 9.* Adding 2nd Echelon Units screen.

mouse pointer is moved throughout the theater. After all of the desired MTFs are entered, each MTF is numbered and labeled with a "2E" to indicate it is a 2nd Echelon unit. MTFs are numbered sequentially, from left to right and top to bottom, once the OK button is pressed with the LHB.

The next input screen (*Figure 10*) prompts the user to enter the planned evacuation routes, or "links," within the theater. At this point in the simulation, the medical planner needs to determine the specific 2nd Echelon MTFs that are within feasible range of each Troop Node. To help facilitate route placement, the distance between a chosen Troop Node and a 2E MTF is displayed in the Message Bar at the bottom of the Troop Node Linking screen (*Figure 10*).

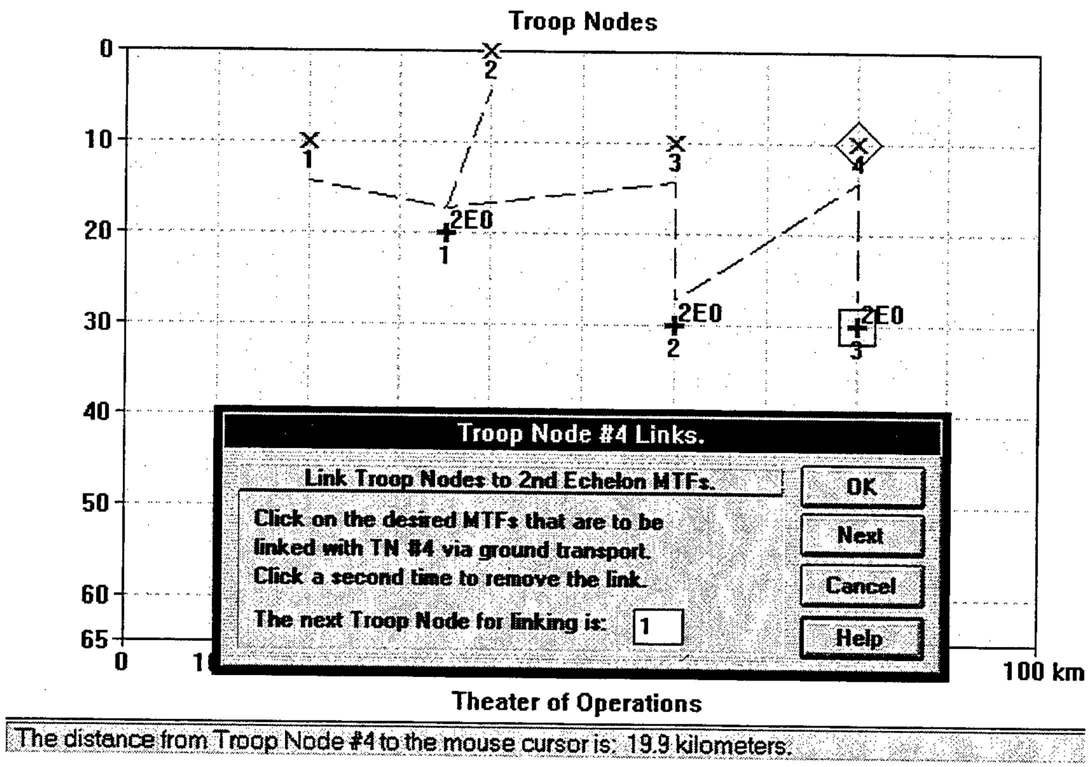



*Figure 10.* Troop Node Linking screen.

Once the user selects a treatment facility to service a Troop Node (which is enclosed in a square, black box), clicking on this MTF with the LHB will cause a black, dashed, straight-line link to appear (clicking a second time on the same MTF with the LHB will, in

turn, remove the link). Then the user has the option to link another MTF to this Troop Node, following the same procedure, or to advance to the next Troop Node. The user may advance to another Troop Node in one of two ways: (a) by clicking on the Next button with the LHB, which advances the user to the next left and topmost Troop Node in the theater, or (b) by clicking inside the input box on the screen, entering the numerical index from the keyboard, and then clicking the Next button with the LHB. Note, as the user cycles through the Troop Nodes, the current node is enclosed in a black diamond. Furthermore, all links for the current node are black, while those for the others are blue.

After the desired link configuration is entered, the Place Beds screen prompts the user to specify the number of beds at each of the previously placed 2nd Echelon MTFs (*Figure 11*). This task is accomplished by entering the number of beds from the keyboard and then clicking on the Next button with the LHB. The process is repeated until the total number of beds at Echelon II is greater than or equal to the projected bed requirements. As the user enters the MTF beds, the bottom Message Bar displays the number of Echelon II beds required, the total number of beds entered so far, and the remaining number of beds needed. The simulation does not advance until at least the required number of beds is placed. Previously designated bed quantities can be easily changed by clicking within the data input box and entering the desired quantity via the keyboard. *Figure 11* shows sample data for 2nd Echelon MTF #1.

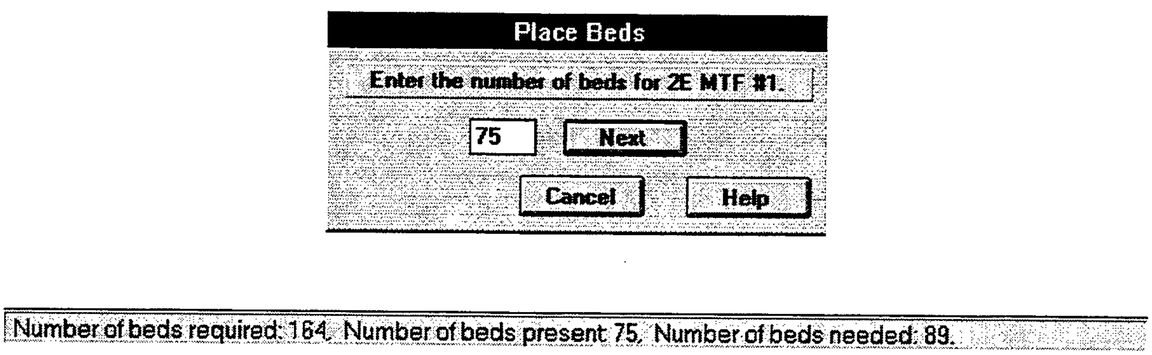



*Figure 11.* Place Beds screen.

After the user places the required number of beds at each MTF, the simulation proceeds to display the MTF-specific bed quantities immediately to the right of each MTF on the theater grid.

The Evacuation Vehicles screen (*Figure 12*) prompts the user to enter information regarding five common evacuation ambulance types available for the proposed operation. For other ground asset types, the user can choose either **Other Vehicle 1** or **Other Vehicle 2**. For other *air* asset types, the user must choose the **Other Vehicle 2** category. The following information must be entered for each vehicle type:

1. *Available Quantity – This value for (a) ground vehicle types represents the desired percentage of each type (must sum to 100%) and (b) for air vehicle types, represents the available number of each type. This value must be between 0 and 99.*

2. *Requested Minimum – This value represents the minimum number of a given asset type that the planner desires to be deployed over the entire echelon of care.*

*For the two Other Vehicles categories, the planner must also specify:*

3. *Litter Capacity – This quantity represents the number of stretcher patients a vehicle can hold at one time.*

*Figure 12* displays a scenario requiring M113s, M996 HMMWVs, and UH-60A Blackhawks. To enter values in each box of this screen, the user must click on the appropriate box, and then enter a value from the number pad on the keyboard. Alternatively, the user can cycle through each input box by pressing the Tab key after entering the appropriate value.

Having entered all of the required input data, OPTEVAC automatically runs when the OK button is clicked with the LHB on the Evacuation Vehicles input screen. The Theater Evacuation Vehicles output screen for 2nd Echelon is then displayed (*Figure 13*). The output screen consists of five columns and lists, from left to right, the evacuation vehicle type names, the minimum number of each asset type to be deployed at a given MTF, the

total required for each asset type throughout the echelon of care, the available quantity of each asset, the requested minimum number of each vehicle, and litter capacity of each

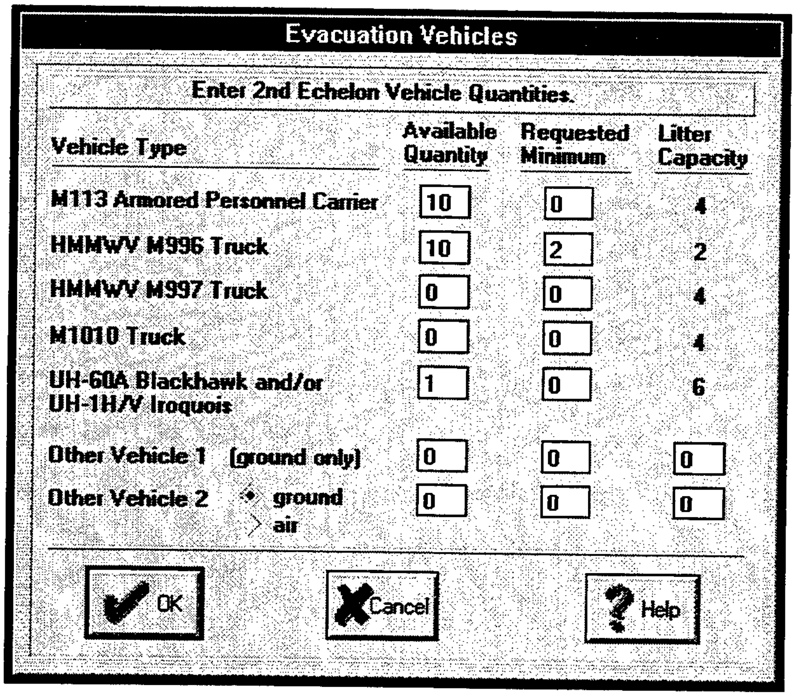



*Figure 12.* Evacuation Vehicles screen.

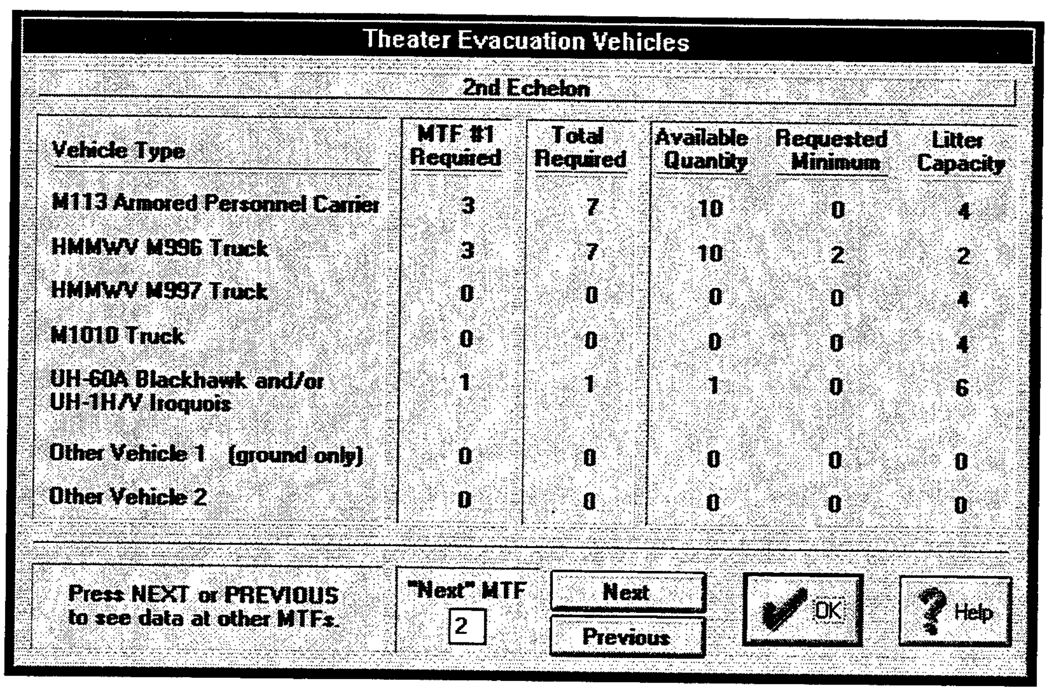



*Figure 13.* Theater Evacuation Vehicles output screen.

ambulance type.

The user may view the minimum vehicle requirements for the other MTFs in one of three possible ways: (a) by pressing the Next button with the mouse to advance, for example, from MTF #1 to MTF #2; (b) by pressing the Previous button with the LHB if the planner decides to review vehicle requirements for a previous MTF; or (c) by entering the MTF node desired in the square input box on the bottom center of the screen and then pressing the Next button with the LHB.

To determine evacuation asset requirements for Echelon III, the user must follow the same sequence of input screens as for Echelon II: the simulation calculates the number of 3rd Echelon beds necessary to accommodate the projected patient flow, prompts the user to place the evacuation routes and MTFs, and finally requests information on the available evacuation assets at this level of care. Consequently, the 2nd to 3rd Echelon Linking screen is very similar to that for the Troop Nodes (*Figure 14*).

Once all Echelon III input has been entered, the proposed combat scenario is complete. A final screen, the Theater Scenario screen, displays the theater with its Troop Node and MTF locations along with their corresponding evacuation routes for easy review (*Figure 15*). In this example scenario, two 3rd Echelon MTFs were placed, each having 90 beds.

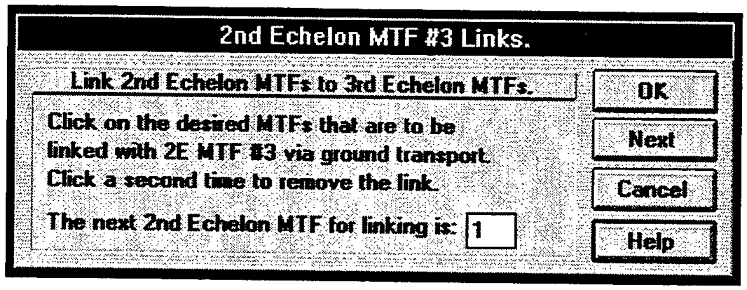



*Figure 14.* 2nd to 3rd Echelon Linking screen.

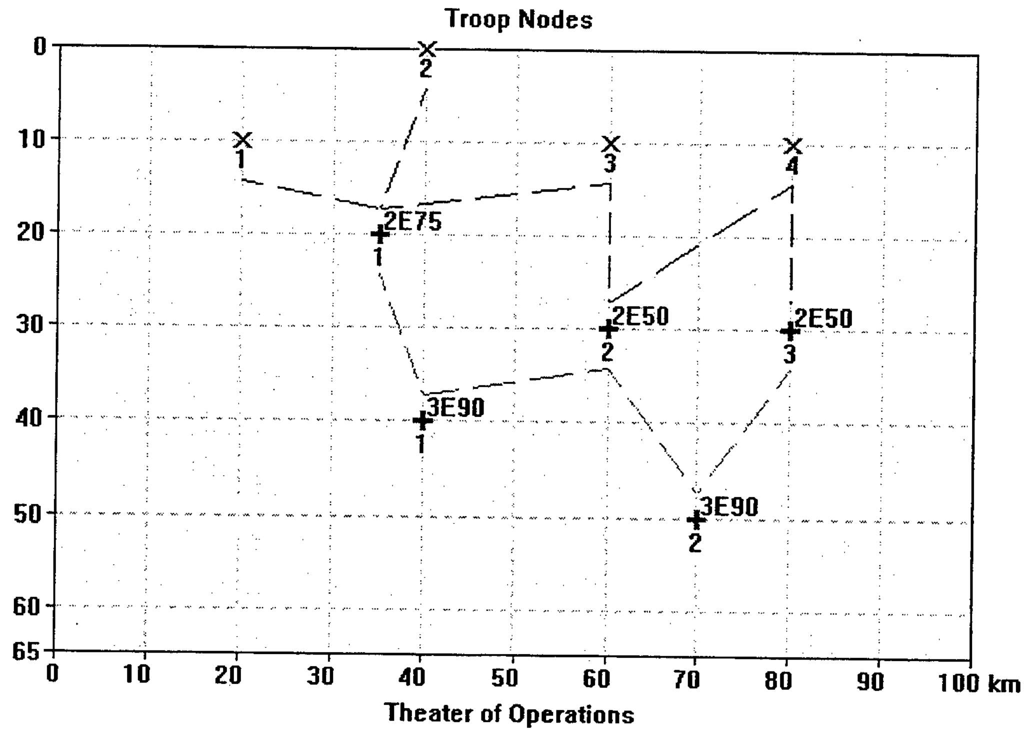



*Figure 15.* Theater Scenario screen.

The evacuation routes that were entered are always displayed as the default option. If the link configuration for a given scenario is particularly dense, however, the user may toggle off the link display. This is performed using the Options menu (see the Appendix). Similarly, if desired, the user may click on the Edit menu with the LHB to modify any of the previously entered information (*Figure 16*), and run the simulation again with the new input.

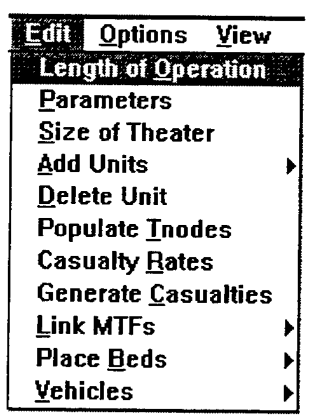



*Figure 16.* Edit menu.

## PART II – MATHEMATICAL FRAMEWORK AND STATISTICAL ASSUMPTIONS

For future combat scenarios, medical evacuation planning requires deciding upon the strategic locations of the casualty collection points, treatment facilities, and evacuation routes. Once this information has been determined, one must calculate the necessary quantities of ground and air evacuation assets that must be stationed at each MTF. Air assets have large ranges, so placement of them is not critical. Ground assets, however, have more limited ranges and, therefore, need to be stationed at the most appropriate MTF within the theater. To conserve resources, it is desirable to find the minimum required ground assets. The problem then is to identify the most appropriate locations for each ground evacuation asset type once the user specifies each of their relative proportions. To ensure that the expected casualties may be transported efficiently, these minimum required ground assets must be stationed at each MTF so that all demand locations have at least one ambulance sufficiently nearby that is available to make an evacuation trip. Mathematically, this problem can be formulated as a linear or integer programming problem, the objective being to minimize the required ground assets for each echelon subject to a series of demand constraints.

A comprehensive examination of existing location covering models was conducted,[4] and the Probabilistic Location Set Covering Problem (PLSCP)[2,3] was chosen as the baseline model. The PLSCP is a model assuming the probability at least one ground ambulance is available for emergency service within demand region "*i*" is 95%. Mathematically, this <u>nonlinear</u> constraint (known as the reliability constraint) is stated as,

$$1 - \left(\frac{F_i}{b_i}\right)^{b_i} \geq .95, \ \forall i \in I,$$

where:

$$F_i = \frac{1}{8}\bar{t} \sum_{k \in M_i} f_k, \ \forall i \in I,$$

and

$b_i$ = the minimum number of evacuation assets required within demand (or troop) region $M_i$, which simultaneously solves the above reliability constraint.

Also,

i, I = *index and set of all Demand (or Troop) Node sites,*

$\bar{t}$ = *the average duration (hours) of a trip within the theater (average distance between each linked Troop Node and MTF site / the weighted average speed of the available evacuation assets, using the percentages of available evacuation assets entered by the user),*

$f_k$ = *frequency of casualty trips at Demand (or Troop) Node k (trips/day),*

$S$ = *the maximum distance (or time) standard within which a unit (Troop Node or MTF) is desired to be found, and*

$M_i$ = *the set of Demand (or Troop) node sites within S of Demand (or Troop) Node site i.*

The number, 8, in the denominator of $F_i$ represents the average amount of time (in hours) a given ambulance spends making evacuation trips in a given day. With this definition of $F_i$, the ratio $\left(\frac{F_i}{b_i}\right)^{b_i}$ is often called the "busy fraction" of all the region's evacuation assets.[2,3] The busy fraction is the probability that all of the ambulances within range of demand region "*i*" are busy making an evacuation call. Therefore, this value subtracted from 1 is the probability that at least one ambulance will be available to make a trip to node site *i* with 95% certainty. This minimum probability is often called the "vehicle reliability." Since the reliability constraint has no closed-form solution, it must be solved for $b_i$ numerically, using a standard root-finding technique, such as the Newton-Raphson method.[9]

Once all of the $b_i$'s are found, finding the minimum number of ground evacuation ambulances can be found by solving the following integer programming problem:

Minimize:

$$z = \sum_{j \in J} x_j ,$$

subject to the <u>linear</u> constraints:

$$\sum_{j \in N_i} x_j \geq b_i \quad \forall i \in I$$

where:

$z$ = *the total number of evacuation assets distributed over all of the facilities in the theater of operations,*

$x_j$ = *the number of evacuation assets at MTF site j ,*

$j, J$ = *index and set of all MTF sites,*

$S$ = *the maximum distance (or time) standard within which a unit (Troop Node or MTF) is desired to be found, and*

$N_i$ = $\{ j \mid d_{ji} \leq S \}$; *the set of MTF sites within S of Troop Node site i, where*

$d_{ji}$ = *the distance (or time) between MTF site j and Troop Node site i.*

Therefore, the minimum number and placement of evacuation assets using this model is based on the anticipated casualty load, an ambulance's availability (or "reliability"), and the size of the service area.

The PLSCP is a model usually applied to urban evacuation planning, and so it assumes a single ground evacuation vehicle type holds only one patient at a time. Consequently, the model was extended when multiple ground ambulance types, each with distinct litter capacities, are involved, as is often the case in military operations.

In the case of multiple ambulance types, the nonlinear reliability constraint,

$$1 - \left(\frac{F_i}{b_i}\right)^{b_i} \geq .95, \ \forall i \in I,$$

remains exactly the same, except now it applies collectively to all types involved (here, $b_i = \sum_{i \in I, v \in V} b_{i,v}$, where $b_{i,v}$ = the minimum number of evacuation assets required within region $M_i$ and of ambulance type $v$). In other words, the probability of at least one ground vehicle type being available to make an evacuation call is 95%. $F_i$ can now be written as:

$$F_i \quad = \quad \frac{1}{8}\bar{t} \sum_{k \in M_i, v \in V} f_{k,v}, \ \forall i \in I,$$

where:

$f_{k,v}$ = *frequency of casualty trips, at Troop Node k (trips/day) and of ambulance type v, and*

$v, V$ = *index and set of all evacuation ambulance types. All other variables are defined as before.*

Computation of the quantity $f_{k,v}$ is shown in detail in a previously written report.[4] A methodology was then developed to find the corresponding $b_{i,v}$'s for each specific vehicle type. The quantity $b_{i,v}$ is determined from the system of equations involving the availability ratios of each vehicle type:

$$\sum_{i \in I, v \in V} b_{i,v} = b_i \text{, and}$$

$a_{v/n}\, b_{i,n} = b_{i,v}$, for each vehicle type, v, other than n, where $a_{v/n}$ is the availability ratio with respect to the vehicle type, n.

Since $F_i$ depends on the expected casualty load, $b_{i,v}$ will, in turn, vary accordingly.

Once these $b_{i,v}$'s are derived, the mathematical formulation of the extended version of the PLSCP, or PLSCIP (Probabilistic Location Set Covering Integer Program), when multiple asset types are involved, can be stated similarly as follows:

Minimize:

$$z_v = \sum_{j \in J} x_{j,v} \quad \text{for each } v \in V,$$

subject to the <u>linear</u> constraints:

$$\sum_{j \in N_i} x_{j,v} \geq b_{i,v} \quad \forall i \in I, \text{ for each } v \in V,$$

where:

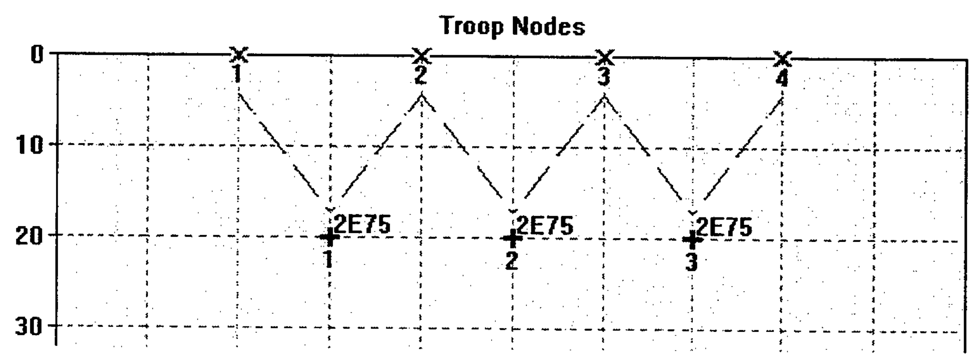
$z_v$ = *the total number of evacuation assets of vehicle type v distributed over all of the facilities in the theater of operations, and*

$x_{j,v}$ = *the number of evacuation assets at MTF site j and of ambulance type v.*

All other variables are defined exactly the same as for the original PLSCP.

Thus, the PLSCIP applies the PLSCP algorithm iteratively for each available ground ambulance type. The PLSCIP, since it is an *integer* program, is conventionally solved using branch-and-bound methods. The standard way to check whether branch-and-bound methods are necessary, however, is to determine whether the constraint matrix is unimodular (eg, every subdeterminant of the constraint matrix must be 0, 1, or -1). The unimodular condition, together with the integral right-hand side values of the constraints, ensures that the corresponding *linear* program (eg, its LP-relaxation) has an integer solution. Although the right-hand side values ($b_{i,v}$ s) for the constraints of the PLSCIP are always positive integers, its constraint matrix is not always unimodular. However, the PLSCIP is "integer friendly"[10](also, Charles ReVelle, Professor, The Johns Hopkins University, personal communication, 1995), meaning the corresponding linear program yields integer solutions. Therefore, the authors chose to use a numerical implementation of the Simplex Method[9] to solve each of the ground asset types' individual integer programs.

Once the minimum quantity of each ground vehicle type is derived, they are placed at specific Echelon II and III MTFs based on the user-entered evacuation route configuration and the predicted daily casualty load. For example, for the simple combat scenario depicted below involving four troop deployment nodes and three Echelon II MTFs, we make the following calculations, assuming casualty loads at Troop Nodes 1 through 4 of 5000, 1000, 1000, and 5000, respectively (and so 12000 casualties, total).




Calculations for Echelon II MTF #1:

Five thousand casualties will be transported from Troop Node #1, and 500 casualties (or 50% of all casualties incurred at Troop Node #2) need to be transported from Troop

Node #2 for medical care at Echelon II MTF #1. Therefore, a total of 5500 casualties require transport, and so 5500/12000 ≈ 46% of all minimally derived totals of ground evacuation asset types will subsequently be sited at this MTF. This calculation is then repeated for the remaining Echelon II MTFs.

Echelon II MTF #2:

Approximately 500 casualties will be transported from Troop Node #2, and 500 casualties need to be transported from Troop Node #3 (or 50% of all casualties incurred at Troop Nodes #2 and #3) for medical care at this MTF. Therefore, a total of 1000 casualties require transport, and so 1000/12000 ≈ 8% of all minimally derived totals of ground evacuation types will subsequently be sited at this MTF.

Echelon III MTF #3:

Approximately 500 casualties will be transported from Troop Node #3 (or 50% of all casualties incurred there) and 5000 casualties need to be transported from Troop Node #4 for medical care at this MTF. Therefore, a total of 5500 casualties require transport, and so 5500/12000 ≈ 46% of all the minimally derived totals of ground evacuation types will subsequently be sited at this MTF.

Since air assets are typically few in number and are the most desirable evacuation asset because of their large range, the OPTEVAC simulation tool was designed to use all of the available air assets before determining any additional ground asset requirements from the PLSCIP. The following formula is used to determine the number of patients a given quantity of air assets can transport in an eight-hour work day:

$$\frac{AQ \times LC \times AS \times T}{AD}$$

| | | | |
|---|---|---|---|
| *where:* | $AQ$ | = | *the number of available air assets,* |
| | $LC$ | = | *the litter capacity of the chosen air asset,* |
| | $AS$ | = | *the air speed, assumed to be 150 km/hr (this speed includes loading and unloading time*[8]*),* |
| | $T$ | = | *total time of service = 8 hr/day, and* |
| | $AD$ | = | *the average (round trip) distance.* |

The quantity *AD* is determined by taking the average distance between each MTF and all of its associated patient collection points. The available air assets are then placed at the closest possible MTF.

If dedicated air assets are available but are not sufficient to transport the projected casualty load, OPTEVAC implements the PLSCIP to determine the minimum numbers of additional ground assets required.

In addition, to account for occasionally unforeseen events when predicting the ground asset requirements, OPTEVAC uses a quantity called the Dispersion Factor. This factor depends on the Dispersion Allowance, which is defined as the percentage of ambulances in the force that are expected to be unavailable at any given time due to maintenance, crew rest, combat loss, or replacement lag time.[8] This information is requested during the Operation Parameters process of the simulation, as mentioned in Part I. OPTEVAC computes the dispersion factor using the following formula:

$$DF = \frac{1}{1 - DA}$$

*where:* $DA$ = *the Dispersion Allowance, and*
$DF$ = *the Dispersion Factor.*

Thus, when the Dispersion Allowance is 20%, the corresponding dispersion factor is 1.25, which is multiplied times the projected minimum number of ground vehicles at each echelon.

Separate algorithms are also necessary to determine bed requirements. Casualties are classified into two broad categories: WIA and DNBI, which are generated using the methodology underlying the FORECAS[1] software, and are assumed to be derived from an exponential and lognormal distribution, respectively. The sum total of these two admission types represents the patients needing evacuation. The bed requirement algorithms are developed from the simple principle that some casualties entering a facility are returned to duty from that treatment center while others are evacuated to higher echelon facilities for further care. The length of time patients stay for primary care at each echelon depends on the severity of the medical condition and two operational parameters: the Evacuation

Delay and the Theater Evacuation Policy. Raising the Evacuation Delay results in a greater accumulation of patients in the forward hospital units, while increasing the Theater Evacuation Policy tends to move fewer patients from the theater and returns more patients to duty within the theater.[6,7] *Table 1* displays the iterative formulas needed to calculate Echelon II bed requirements when Evacuation Delays range between 1 and 4 days. Formulas are easily extended for Evacuation Delays between 5 and 15 days.

The iterative formulas for Echelon III resemble those of the previous echelon and depend on the Theater Evacuation Policy entered by the user as well as the delay D at Echelon II. Thus, the number of Echelon III admissions from day 1 to D will be 0, since those casualties are still being treated and/or stabilized at Echelon II facilities, and for days larger than D, the formulas will parallel those listed for Echelon II in *Table 1*.

## PART III – VERIFICATION OF THE OPTEVAC MODEL

The PLSCIP algorithm for determining the minimum required ground assets was tested for the theater scenario depicted in *Figure 15* of Part I of this report for three different casualty loads. Output was then compared with the expected casualties that can be transported by two ground ambulances types for several reliability levels (specifically, 99%, 90%, 80%, and 50%). OPTEVAC's results appeared to perform especially well for high casualty rates.

For the scenario shown in *Figure 15*, the following input parameters were chosen: a 10-day duration, a 99% casualty load, and 5000 troops were at risk at each of the four Troop Nodes. The expected WIA casualty rates were initially set at 5 (the two other tests were for casualty rates of 10 and 15). Two ground vehicle types, the M113 armored personnel carrier and the M996 HMMWV, were chosen in equal ratio (1:1) for the scenario's evacuation demands.

The corresponding PLSCIP is set up as follows for each asset type:

$$\text{minimize} \quad z = x_1 + x_2 + x_3$$

subject to the following constraints:

$$x_1 \geq b_{1,v},$$

$$x_1 \geq b_{2,v},$$

$$x_1 + x_2 \geq b_{3,v}, \text{ and,}$$

$$x_2 + x_3 \geq b_{4,v},$$

for both v = M113 and v = M996. Since more than one asset type is involved, each $b_{i,v}$ is determined from solving the nonlinear reliability constraint and system of equations mentioned in Part II of this report in addition to the algorithms derived from a previously written report.[4] The M-regions of demand consist of the following: $M_1$ = Troop Nodes 1 and 2, $M_2$ = Troop Nodes 1, 2, and 3, $M_3$ = Troop Nodes 2, 3, and 4, and $M_4$ = Troop Nodes 3 and 4.

The following casualty "threshold" calculations were made:

$$\frac{4 \times 16 \times 8}{44.46} \approx 12 \text{ casualties, for one M113 ambulance, and}$$

$$\frac{2 \times 16 \times 8}{44.46} \approx 6 \text{ casualties, for one M996 ambulance.}$$

In this calculation, the numerator represents the litter capacity times the speed of the vehicle times the hours of service in a day, and the denominator is the average round trip distance for this scenario in kilometers. Thus, one M113 ambulance and one M996 ambulance collectively can transport a maximum of about 18 casualties in a given 8-hour service day.

*Table 2* displays the results for three trial runs. To compute the "Threshold Solution" assuming a WIA casualty rate of 5.0 at each Troop Node, for example, we make the following calculation:

$$172/18 \approx 10, \text{ yielding } 10 \times (12 + 6) \equiv 10 \times (1 \text{ M113} + 1 \text{ M996}),$$

and therefore 10 M113s and 10 M996s are required to transport the expected casualty load. Threshold Solution values in *Table 2* for each of the other casualty rate runs are similarly computed. For ratios other than a 1:1 ratio and for N vehicle types, the calculation above would become in general:

$$\text{Threshold Solution} = \frac{\textit{Casualty Load}}{\sum_{i=1}^{N} v_i t_i}$$

where $v_i$ and $t_i$ are the proportion and threshold number of casualties that can be transported for vehicle type, i, respectively.

As can be seen from *Table 2*, OPTEVAC's predictions do indeed minimize the number of required ground evacuation assets. OPTEVAC appears to perform well for large casualty loads. In all test runs, OPTEVAC's predicted asset requirements are smaller than the computed Threshold Solution. Output is displayed for five different reliability levels. One would expect then as the reliability level is relaxed, less ground evacuation assets would be needed (since more of them are then allowed to be busy), which is indeed the trend shown in *Table 2*. These OPTEVAC values, as stated in the mathematical formulation of the PLSCIP in Part II of this report, would thus additionally ensure that at least one evacuation asset will be available to make an evacuation call $\alpha$% of the time.

*Table 1.* **Iterative formulas for Echelon II bed requirements (1-4 day Evacuation Delays). ***

| | Echelon II Bed Requirements |
|---|---|
| Evacuation Delay | WIA Presentations |
| 1 day | $(.696)C_N$ (Day 1 through N) |
| 2 days | $(.696)C_1$ (Day 1)<br>$(.696)C_N + (.67 \times .696)C_{N-1}$ (Day 2 through N) |
| 3 days | $(.696)C_1$ (Day 1)<br>$(.696)C_2 + (.67 \times .696)C_1$ (Day 2)<br>$(.696)C_N + (.67 \times .696)C_{N-1} +$<br>$(.648 \times .67 \times .696)C_{N-2}$ (Day 3 through N) |
| 4 days | $(.696)C_1$ (Day 1)<br>$(.696)C_2 + (.67 \times .696)C_1$ (Day 2)<br>$(.696)C_3 + (.67 \times .696)C_2 + (.648 \times .67 \times .696)C_1$ (Day 3)<br>$(.696)C_N + (.67 \times .696)C_{N-1} + (.648 \times .67 \times .696)C_{N-2} +$<br>$(.624 \times .648 \times .67 \times .696)C_{N-3}$ (Day 4 through N) |
| Evacuation Delay | DNBI Presentations |
| 1 day | $(.997)C_N$ (Day 1 through N) |
| 2 days | $(.997)C_1$ (Day 1)<br>$(.997)C_N + (.935 \times .997)C_{N-1}$ (Day 2 through N) |
| 3 days | $(.997)C_1$ (Day 1)<br>$(.997)C_2 + (.935 \times .997)C_1$ (Day 2)<br>$(.997)C_N + (.935 \times .997)C_{N-1} +$<br>$(.886 \times .935 \times .997)C_{N-2}$ (Day 3 through N) |
| 4 days | $(.997)C_1$ (Day 1)<br>$(.997)C_2 + (.935 \times .997)C_1$ (Day 2)<br>$(.997)C_3 + (.935 \times .997)C_2 + (.886 \times .935 \times .997)C_1$ (Day 3)<br>$(.997)C_N + (.935 \times .997)C_{N-1} + (.886 \times .935 \times .997)C_{N-2} +$<br>$(.812 \times .886 \times .935 \times .997)C_{N-3}$ (Day 4 through N) |
| where: | $N$ = total number of days of the operation, and<br>$C_i$ = number of admissions expected for day i. |

***Formulas are based on the percentage of presentations returning to duty during the Vietnam War.[5]**

*Table 2.* – **OPTEVAC test run results for three different casualty rates.**

**WIA Casualty Rate = 5.0***

| Casualty Load | Threshold Solution | **OPTEVAC Solutions: 99% Level | 90% Level | 80% Level | 50% Level |
|---|---|---|---|---|---|
| 172 | 10 M113s<br>10 M996s | 9 M113s<br>9 M996s | 9 M113s<br>7 M996s | 7 M113s<br>7 M996s | 7 M113s<br>5 M996s |

**WIA Casualty Rate = 10.0***

| Casualty Load | Threshold Solution | 99% Level | 90% Level | 80% Level | 50% Level |
|---|---|---|---|---|---|
| 343 | 19 M113s<br>19 M996s | 15 M113s<br>14 M996s | 14 M113s<br>12 M996s | 12 M113s<br>12 M996s | 12 M113s<br>10 M996s |

**WIA Casualty Rate = 15.0***

| Casualty Load | Threshold Solution | 99% Level | 90% Level | 80% Level | 50% Level |
|---|---|---|---|---|---|
| 515 | 29 M113s<br>29 M996s | 21 M113s<br>19 M996s | 19 M113s<br>17 M996s | 17 M113s<br>17 M996s | 17 M113s<br>15 M996s |

***Casualty rates were set at the given value for all four Troop Nodes.**
**** % Level = The % of time at least one vehicle is available to make a service call.**

## CONCLUSIONS

The OPTEVAC software is a user-friendly tool for estimating the evacuation asset requirements during combat deployments. OPTEVAC's GUI is a highly interactive and visual environment, prompting the user to enter the critical planning factors needed to make realistic bed requirement and transportation asset projections. Tests verified its minimum required ground asset predictions are sufficient but not excessive. Together, OPTEVAC's flexible simulation methodology and data-driven algorithms make it an excellent device for determining the medical resource requirements of future military operations.

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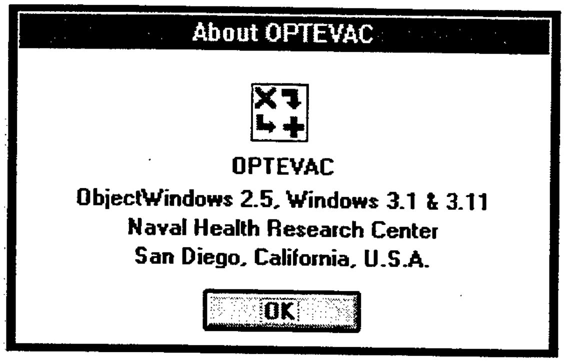
## APPENDIX

OPTEVAC System Requirements and Installation




Minimum System Requirements:

- an IBM-compatible PC
- a VGA monitor
- 8 MB of RAM
- Windows 3.1 OR 3.11
- 2.5 MB of disk space
- Microsoft-compatible mouse

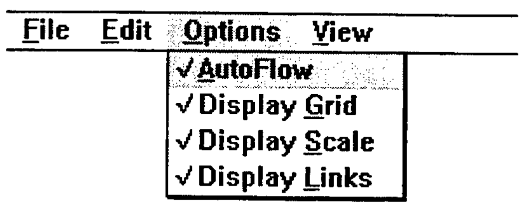
### Installation

OPTEVAC is distributed on disk as a compressed file that contains six essential files: an executable (.exe) file called "optevac.exe," four different Dynamic Link Library (.dll) files, and one Help (.hlp) file. The .dll files have the following names: bc450rtl.dll, bids45.dll, bwcc.dll, and owl252.dll, while the .hlp file is named "oe_help.hlp." Installation is accomplished by inserting the 3.5-inch floppy disk into the disk drive. OPTEVAC is a Windows application, and as such, must be run from the Windows (either Version 3.1 or 3.11) environment. While in the Windows *Program Manager*, the user must select the File menu, and click on Run. Next, the user must enter "A: INSTALL" (without the quotes). A series of screens will automatically appear and guide the user step-by-step through the proper installation procedure, so that all of the required files are loaded onto the hard drive of the computer.

## Setup

OPTEVAC is a Windows application, and as such, must be run from the Windows environment. When the software is properly installed on the computer, check the list of file directories within *File Manager* and look for one named "OPTEVAC," which will contain the four Dynamic Link Library (.dll) files, a "readme.txt" file documenting the software, the Help file (optevac.hlp), as well as the executable file. Within the *Program Manager* for Windows, a program group named "NHRC Simulators" should appear and display the OPTEVAC icon. The user must then double-click on this icon with the left-hand button (LHB) on the mouse to begin the simulation.

The user can advance through the program in two different ways, or modes, with frequent use of the mouse and its LHB. In the "AutoFlow" mode, the user proceeds automatically from one input screen to the next until the final vehicle requirements are determined for the chosen scenario. In the Menu Selection mode, the user may proceed through the simulation a screen at a time by clicking on the Edit menu and selecting the input data they would like to modify. The OPTEVAC system default mode of operation is the AutoFlow mode, which may be toggled on or off by clicking on AutoFlow under the Options menu, as shown here.





The top bar is called the Menu Bar and appears at the top of each user screen; the bottom gray bar is the Message Bar, and it appears at the bottom of each screen.

For most input screens, the user has the option to click three distinct buttons: OK, Cancel, and Help with the LHB (shown here).


Clicking the OK button stores the entered data and advances to the next screen in the simulation, while clicking the Cancel button stops the simulation at the present point. The user can also click the Help button to obtain directions for running each step of the simulation. If one prefers, the "shortcut" keys Tab, Enter, and Escape (ESC) can be pressed on the keyboard. The Tab key allows the user to cycle through each data entry location and button of each dialog box. The Enter key executes the active, or highlighted button. The ESC key works like the Cancel button, effectively stopping the simulation. Before *exiting* the program, the user must first cancel the process they are currently in. Exiting the program can be accomplished in one of three ways: (a) the user can go to the File menu and click the Exit option with the LHB, (b) the user can press the F4 key while pressing the Alt key on the keyboard, or (c) the user can double-click the System Control Box in the upper left-hand corner of the screen.

In addition to clicking the Help button when currently in a specific process, the OPTEVAC Help system may also be accessed in two other ways: (a) by clicking on Help-Index from the Menu Bar, or (b) by pressing the F1 key on the keyboard. Whenever the user enters the Help system from the Menu Bar, the Table of Contents Help Page appears, with topics arranged alphabetically for easy reference. Similarly, pressing the F1 key on the keyboard advances the user to the Table of Contents Help Page.

Whenever the Cancel button is pressed while in the AutoFlow mode, the User Response Box appears (*Figure 1*). At this screen, the user is asked if they want to continue entering information to run the simulation or to break out of the simulation sequence. If the user clicks the Yes button with the LHB, the previous screen will reappear and prompt the user for input. Otherwise, if the user clicks the No button, the

simulation will stop, and the user can choose from the Menu Bar to exit or to proceed in the simulation manually.

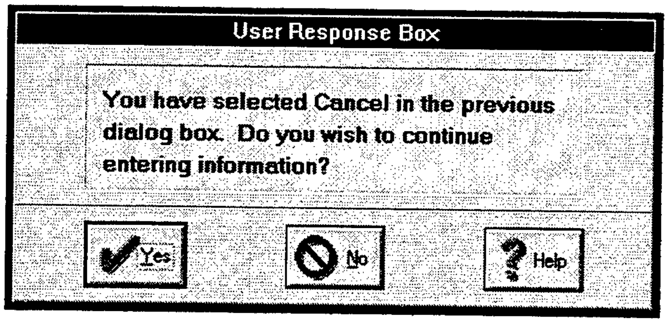



*Figure 1.* User Response Box.

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**13. ABSTRACT** ***(Maximum 200 words)***
Military medical readiness for ground combat operations requires projections of the evacuation assets needed to transport the casualties incurred through the various echelons of medical care. The OPTEVAC planning tool was designed to minimize the required evacuation assets by providing the optimal deployment locations of these transportation assets. This simulation tool utilizes information on the expected casualty rates, the size of theater, the desired troop deployment node and medical treatment facility (MTF) locations, and the types and numbers of available air and ground ambulances to drive the underlying linear programming algorithm which determines the optimal transportation asset locations. More specifically, user input is accomplished by prompting the planner to enter troop deployment and MTF sites as well as the associated evacuation routes on a grid scaled to represent the combat theater. The OPTEVAC software then uses a modified version of the Probabilistic Location Set Covering Problem (PLSCP) to calculate the minimum numbers of ground evacuation assets along with their most appropriate locations at Echelon II and III within the theater.

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